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Stochastic Modelling of Aircraft Ground Time at Soekarno-Hatta International Airport

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Abstract

Ground time plays an important role in keeping flight on-time performance and passenger smooth flow. It varies depending on the aircraft type, procedures, passenger number and/or cargo amount, maintenance requirements, and ground handling service quality. This research aims to explore the ground time distribution pattern at Soekarno-Hatta International Airport. The daily flight historical data is divided into several categories based on the airline's service type for local airlines, the airline's origin for foreign airlines, the type of flight, and aircraft size. Ground time data of each flight category is then fitted to all possible distribution types by using the Distribution Fitting app in Matlab. The best-fitted distribution definition uses the Kolmogorov-Smirnov test by comparing the p-value of each distribution. 6 distributions fit 20 flight categories. Almost all local airlines' ground time except full-service carrier international flights and low-cost carrier international flights with wide-body aircraft fit to Burr distribution. Full-service carrier international flight with narrow and wide-body aircraft, international flight with narrow-body aircraft operated by airlines from China and other countries fit Generalized Extreme Value distribution. Low-cost carrier international flights with wide-body aircraft and private flights fit to Inverse Gaussian distribution. International flights with wide-body aircraft operated by airlines from Korea, Japan, and other countries airlines fit for Nakagami distribution. While the cargo flights fit t Location-Scale distribution for wide-body aircraft and Weibull distribution for narrow-body aircraft. Then the stochastic models are developed based on each flight category's distribution parameters. These models are expected to be able to guide future research in ground time or apron capacity management as they provide the data distribution without more primary data needed.

Keywords: Distribution, Ground Time, Parameter, Probability Density Function

Abstrak

Pemodelan Stokastik Waktu Darat Pesawat di Bandara Internasional Soekarno-Hatta: *Waktu darat memainkan peran penting dalam menjaga kinerja waktu penerbangan tepat waktu dan kelancaran arus penumpang. Waktu darat bervariasi tergantung pada jenis pesawat, prosedur, jumlah penumpang dan/atau jumlah kargo, persyaratan pemeliharaan, dan kualitas layanan penanganan darat. Penelitian ini bertujuan untuk mengeksplorasi pola distribusi waktu darat di Bandara Internasional Soekarno-Hatta. Data historis penerbangan harian dibagi menjadi beberapa kategori berdasarkan jenis layanan maskapai penerbangan lokal, asal maskapai penerbangan asing, jenis penerbangan, dan ukuran pesawat. Data waktu darat dari setiap kategori penerbangan kemudian disesuaikan dengan semua jenis distribusi yang mungkin menggunakan aplikasi Distribution Fitting dalam Matlab. Definisi distribusi yang paling cocok menggunakan uji Kolmogorov-Smirnov dengan membandingkan nilai p dari setiap distribusi. Enam distribusi cocok dengan 20 kategori penerbangan. Hampir semua waktu darat maskapai penerbangan lokal kecuali penerbangan internasional maskapai penuh dan penerbangan internasional maskapai berbiaya rendah dengan pesawat berbadan lebar cocok dengan distribusi Burr. Penerbangan internasional maskapai penuh dengan pesawat berbadan sempit dan berbadan lebar, penerbangan internasional dengan pesawat berbadan sempit yang dioperasikan oleh maskapai dari China dan negara-negara lain cocok dengan distribusi Generalized Extreme Value. Penerbangan internasional berbiaya rendah dengan pesawat berbadan lebar dan penerbangan swasta cocok dengan distribusi Inverse Gaussian. Penerbangan internasional dengan pesawat berbadan lebar yang dioperasikan oleh maskapai dari Korea, Jepang, dan maskapai dari negara-negara lain cocok dengan distribusi Nakagami. Sementara itu, penerbangan kargo cocok dengan distribusi Lokasi-Skala untuk pesawat berbadan lebar dan distribusi Weibull untuk pesawat berbadan sempit. Kemudian model stokastik dikembangkan berdasarkan parameter distribusi setiap kategori penerbangan. Model-model ini diharapkan dapat memandu penelitian masa depan dalam manajemen waktu darat atau kapasitas apron karena menyediakan distribusi data tanpa memerlukan data primer lebih lanjut.*

Kata kunci*: Distribusi, Waktu Darat, Parameter, Fungsi Kepekatan Probabilitas*

1. Introduction

Turnaround time (hereinafter referred to as ground time), is the period starting from parking brakes on after arrival to the door closing for departure. It plays an important part in flight on-time performance and smooth passenger flow. The usual ground time of long-haul flights with large aircraft is around 90-120 minutes, while short-haul flights with small aircraft take 25 to 40 minutes [1]. The ground time may vary from one flight to another, depending on several factors, such as aircraft type, local procedures, the number of passengers and/or cargo, necessary maintenance, ground handling manpower and equipment,

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etc. According to the IATA Knowledge Hub article [2], three common causes trigger a delay in ground time: missing passengers, inappropriate ground handling service time, and aircraft ground failure.

Soekarno-Hatta International Airport (IATA: CGK, ICAO: WIII) is the primary airport serving the Jakarta metropolitan area on the island of Java in Indonesia. This airport is operated by PT Angkasa Pura II. Based on a 2022 report from the Port Authority of New York and New Jersey, Soekarno-Hatta International Airport is ranked as the 27th busiest airport in the world by passenger traffic, with a total of 38,791,168 passengers in a year [3]. This airport is also certified as a 3-Star Airport for facilities, comfort, cleanliness, shopping, food & beverages, staff service, and security/immigration by Skytrax [4]. As the main hub airport in Indonesia which has a role as the primary gate of passengers entering and leaving the country and connecting the domestic flights from far east to the west end of Indonesia, there are a lot of airlines operating various types of aircraft in this airport. According to flight approval issued by the Directorate General Civil Aviation (DGCA) of Indonesia for the Summer 2023 season, Soekarno-Hatta International Airport covers 42 destinations of domestic flights and 42 destinations abroad covered by 53 airlines. The domestic flights are served by 10 local airlines, while the international flights are provided by 37 foreign airlines and 6 local airlines. 6 air transport operators specialize in freight. With numerous players who have their own operational procedures and service levels, the ground time of each flight certainly will vary depending on the airlines' operational strategy. With the uncertainty of ground time, it is difficult to standardize the airport's apron capacity based on the arriving and departing aircraft daily. Even though the schedule of regular flights has been defined before the season starts, in actuality the time when aircraft arrives and departs is diverse. Therefore, the purpose of this research is to discover the ground time pattern in Soekarno-Hatta International Airport according to the type of service provided, the origin of the airlines, the flight type, and the aircraft size. The pattern will be conceived in stochastic models based on the best-fitting distribution of the data. The ground time pattern can give benefits for other research which requires ground time as the variable without needing to collect raw data to start.

Figure 1 *Flight categories*

Airline Category		Flight Type	Aircraft Size
Local Airlines (based on type of service)	Full-service carrier Medium service carrier Low-cost carrier	Domestic International	Narrow Body Wide Body
Foreign Airlines (based on airlines' origins)	Southeast Asia China Korea-Japan Middle East Others (Australia, Europe, Africa, Other Asia countries)		
Cargo			
Private Flight			

2. Methodology

The data source for this paper is the primary data from daily flight historical data from May 2023 until July 2023. On the raw data of daily flight traffic, the ground time of each aircraft is not stated explicitly. It is acquired by subtracting the aircraft's actual off-block time from the actual in-block time. Actual in-block time (AIBT) is the recorded time when the aircraft arrives at the designated parking stand and actuate the parking brake. Actual off-block time (AOBT) occurs when the aircraft releases its parking brake to push back and then depart, so the parking stand turns available to be used [5].

2.1. Data Grouping

Each entity in daily flight data is identified by the flight number for arrival and departure, the aircraft's type registration number, origin, and destination airports. From these identifications, each data can discover its operator, type of aircraft, and type of flight (domestic or international). To discover the characteristics of certain types of airlines in terms of how long the aircraft occupies a parking stand from an arrival flight until it is ready for departure, the ground time data is grouped based on the airline categories, types of flights, and aircraft sizes. The data categories are presented in Table 1. Overall, 20 flight categories are formed with the combination of all grouping bases and the criteria presence in the data.

2.2. Data Processing

Ground time data of each flight category is processed by using Matlab to define its distribution model. The distribution Fitter app in Matlab is specifically used to fit the data to several distribution types. This app provides an interactive approach to fit univariate distributions to data with 22 built-in distribution types. The fitted distribution can be displayed visually by graphs and its parameter values can be extracted [6].

The distribution Fitter app in Matlab uses the maximum likelihood method. It is the most common method used in fitting univariate distribution to the data. Suppose a random sample $X_1, X_2, \dots, X_n$ from a distribution with parameter θ and $x_1, x_2, \dots, x_n$ are the observed values of $X_1, X_2, \dots, X_n$. If $X_1, X_2, \dots, X_n$ are continuous random variables, the likelihood function of observed sample probability as a function of θ is:

$$L(\theta) = L(x_1, x_2, .., x_n) = f X_1, X_2, .., X_n (x_1, x_2, .., x_n; \theta) \quad (1)$$

The maximum likelihood estimate (MLE) of θ is the value that maximizes the likelihood function $L(\theta)$ [7]. In Matlab, the mle function calculates the MLE values by minimizing the negative loglikelihood function of the sample data probabilities X with the given distribution parameters θ.

$$\text{Objective function} = -\log \prod_{x \in X} P(x|\theta) \quad (2)$$

For a full-observed observation, $P(x|\theta) = f(x)$, where f is the probability density function (pdf) with parameters θ [8].

To fit the ground time data to the possible distribution types, firstly the data for each category is imported to the Matlab workspace. Then, it creates a new fit for each category. In the new fit menu in Matlab's Distribution Fitter app, the possible distributions for the processed for a new fit are shown. The applied distribution to the data can be presented in several display types: probability density function (pdf), cumulative probability (cdf), quantile, probability plot, survival function, and cumulative hazard. In this research, the probability density function (pdf) display will be equipped to illustrate the distribution fitting to the ground time data. 18 distribution types can represent the ground time data: Birnbaum-Saunders, Burr, Exponential, Extreme Value, Gamma, Generalized Extreme Value, Generalized Pareto, Half Normal, Inverse Gaussian, Loglogistic, Logistic, Lognormal, Nakagami, Normal, Rayleigh, Rician, t Location-Scale, and Weibull.

2.3. Data Analysis

In favor of finding the best-fit distribution for each flight category ground time, a goodness-of-fit test is required to compare all distribution types. One-sample Kolmogorov-Smirnov test (ktest) in Matlab is used to test whether the data fits a certain distribution type. It is a nonparametric test with the null hypothesis that the data is equal to the hypothesized cumulative density function (cdf) [9]. The Kolmogorov-Smirnov test is determined by the following hypothesis:

H_0 = the data follow a specified distribution

H_a = the data do not follow the specified distribution

The test statistic of Kolmogorov-Smirnov is defined with a function below:

$$D = \max_{1 \le i \le N} \left(F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right) \quad (3)$$

where Y_i is the data points and $F(Y_i)$ is the theoretical cumulative distribution of the tested distribution, where it must be a continuous distribution and the parameters are specified [10]. The test statistic result, D value, is the maximum deviation of the empirical cdf from the input data with the theoretical cdf.

In Matlab's One-sample Kolmogorov-Smirnov test, the ktest function rejects the null hypothesis if the p-value of the test is larger than the significance level α (in this case, it is 5% by default). The function does not compare the test statistic ksstat (D value) with the critical value (cv) because cv is an approximation, so it may lead to a different conclusion than comparing the p-value with the significance level. p-value (p) is the probability that the observed test statistic results in extreme values than the observed value under the null hypothesis. A small value of p-value reduces the reliability of the null hypothesis [9]. Significance level α is the probability of rejecting a null hypothesis when the null hypothesis is correct [11].

In this research, to conduct the one-sample Kolmogorov-Smirnov test, the parameters of each distribution must be known first. After all, parameters are specified for every possible distribution type of each flight category, the kstest function can be executed with the data and distribution parameter values based on the hypothesized cumulative density function (cdf). The best distribution is chosen by comparing the p-value and significance level. The null hypothesis will be rejected (h = 1) when $p \leq \alpha$, or otherwise the kstest fails to reject the null hypothesis (h = 0) [9]. If the null hypothesis is rejected, it means that they do not follow the specified distribution, and otherwise if the null hypothesis fails to be rejected, the specified distribution is compatible with the data. When the hypothesis test results are the same for all distribution types, the choosing criteria to select the best distribution is by comparing the p-value. The distribution with the highest p-value is defined as the best-fit distribution to the tested flight category's ground time data since a high p-value implies a high probability of extreme values from the tested data to be covered by the distribution.

3. Results and Discussion

After the data collection, grouping, processing, and analysis, the best distribution that fits each flight category has been discovered. Based on the distribution fitting and Kolmogorov-Smirnov test to find the best-fitted distribution to flight categories, 6 different types of distribution fit 20 flight categories: Burr, Generalized Extreme Value, Inverse Gaussian, Nakagami, t Location-Scale, and Weibull distribution. The description of each flight category is presented in this chapter. The type of distribution which is fitted to the ground time data the most is the Burr distribution. This distribution type usually fits to data with positive skewness and high kurtosis. It means that the ground time tends to be centered at a quite low value while there are also some outliers with a long turnaround time. Other flight categories show similar behavior.

3.1. Burr Distribution

Burr distribution fits with most flight categories' ground time data. From the total of 20 flight categories, ground time data from 10 categories fit this distribution. Burr Type XII distribution is a three-parameter family of distributions on the positive real number domain, with c and k as the shape parameters and α as the scale parameter [12]. This type of distribution can be used to generate a wide range of skewness and kurtosis values. It relates to several distributions such as Lomax, Compound-Weibull, Weibull-Exponential, Logistic, Loglogistic, Weibull, and Kappa family of distribution [13]. The probability density function of Burr distribution is:

$$f(x|\alpha,c,k) = \frac{\frac{kc}{\alpha}\left(\frac{x}{\alpha}\right)^{c-1}}{\left(1+\left(\frac{x}{\alpha}\right)^{c}\right)^{k+1}}, x>0, \alpha>0, c>0, k>0 \tag{4}$$

Almost all local airlines' ground time with narrow and wide-body aircraft fit this distribution type, except for full-service carrier international flights using both narrow and wide-body aircraft and low-cost carrier international flights with wide-body aircraft. International flights operated by airlines from

Southeast Asia with all aircraft sizes, and from China and the Middle East with-wide body aircraft are also fitted to Burr distribution. As seen on the probability density function (pdf) plots, these categories have positive skewness and high kurtosis, which means that the ground time tends to be centered at a quite low value while there are also some outliers with a long ground time.

3.2. Generalized Extreme Value Distribution

Generalized Extreme Value distribution (GEV) was developed to combine three types of EVDs as continuous probability distributions which limit the distribution of normalized maxima from independent and identically distributed random variables. The three types of distribution resemble different classes of distributions with exponentially decreasing tails (such as normal distribution), polynomial decreasing tails (such as Student's *t* distribution), and finite tails (such as beta distribution). GEV distribution is also known as the Fisher-Tippett distribution. This distribution is described by k as the shape parameter, σ as the scale parameter, and μ as the location parameter [14][15]. Following is the probability density function of GEV distribution:

$$f(x|k,\mu,\sigma) = \left(\frac{1}{\sigma}\right) exp\left(-\left(1+k\frac{(x-\mu)}{\sigma}\right)^{-\frac{1}{k}}\right)\left(1+k\frac{(x-\mu)}{\sigma}\right)^{-1-\frac{1}{k}} \qquad (15)$$

The full-service carrier's ground time for international flights with narrow and wide-body aircraft fits this distribution. International flights with narrow-body aircraft operated by airlines from China and other countries also fit with GEV distribution. The data is spreading with a wide range for this flight category, which means the ground time has a high variability from a short to a long turnaround period.

3.3. Inverse Gaussian Distribution

Inverse Gaussian distribution, also called Wald distribution, is used for nonnegative positively skewed data modeling. This distribution has many similarities with the standard normal distribution that induces the application in inferential statistics [16]. Two parameters represent the distribution, scale parameter (μ) and shape parameter (λ). The inverse Gaussian distribution's probability density function (pdf) is below:

$$f(x|\mu,\lambda) = \sqrt{\frac{\lambda}{2\pi x^3}}\exp\left\{-\frac{\lambda}{2\mu^2 x}(x-\mu)^2\right\} \qquad (20)$$

The ground time data that is fitted to this distribution belongs to local low-cost carrier international flights with wide-body aircraft and private flights with narrow-body aircraft. As presented by the pdf plot, the data probability has positive skewness where the highest probability value takes place at the first bin of the graph.

3.4. Nakagami Distribution

Nakagami distribution is usually used for modeling scattered signals that reach a receiver by multiple paths in communication theory. Nakagami is used to model densely scattered signals. This distribution can be reduced into Rayleigh distribution with more control of the fade extension [17]. There are two parameters used by the Nakagami distribution: shape parameter (μ) and scale parameter (ω). The probability density function is below:

$$f(x|\mu,\omega) = 2\left(\frac{\mu}{\omega}\right)^{\mu}\frac{1}{\Gamma(\mu)}x^{(2\mu-1)}e^{\frac{-\mu}{\omega}x^2} \qquad (23)$$

The ground time of international flights with wide-body aircraft operated by airlines from Korea, Japan, and other countries airlines suits for Nakagami distribution. The data probability is scattered along the data range.

3.5. t Location-Scale Distribution

t Location-scale distribution is usually equipped to model data with heavier tails than normal distribution. It is more sensitive to outliers. The tail shape is described by shape parameter *v* the smaller *v* value is, the heavier the tail becomes. t Location-Scale distribution converges to the normal distribution when the *v* comes up to infinity. Besides shape parameter *v*, this distribution also has two other parameters, location parameter μ and scale parameter σ. This distribution has a close relation with Student's *t* distribution, where if *x* has a t location-scale distribution, then the value of $\frac{x-\mu}{\sigma}$ has a student's *t* distribution with *v* as the degree of freedom. The following is the probability density function (pdf) of the distribution [18]:

$$f(x|\mu,\sigma,\nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sigma\sqrt{\nu\pi}\,\Gamma\left(\frac{\nu}{2}\right)}\left[\frac{\nu+\left(\frac{x-\mu}{\sigma}\right)^2}{\nu}\right]^{-\left(\frac{\nu+1}{2}\right)} \tag{26}$$

In this research, there is only one flight category that fits with this distribution, the cargo flights' ground time data with wide-body aircraft. The data of this flight category has some values that lie far from the data average location μ.

3.6. Weibull Distribution

Weibull distribution is categorized in the two-parameter family of curves. It is commonly used in reliability for a time-to-failure model. Having more flexibility than exponential distribution, it generalizes the exponential model to capture the nonconstant failure rate function [19]. In other words, this distribution can model fluctuations in data probabilities. The two parameters to describe Weibull distribution are scale parameter a and shape parameter b. It can take the third parameter, location parameter *c*, whose value is zero in the two-parameter usage. The probability density function (pdf) of the Weibull distribution is below [20]:

$$f(x|a,b) = \begin{cases} \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} e^{-(x/a)^b} \; if\; x \geq 0, \\ 0 \;\; if\; x < 0. \end{cases} \tag{28}$$

The ground time data that fits this distribution is from cargo flights with narrow-body aircraft. Unlike the other common probability patterns, the ground time data of this flight category has random probability density fluctuation from the lowest to the highest ground time value.

Overall, ground time data is highly variated, even from the same flight category. This kind of data is prone to data outliers. One of the possible causes of this high variability situation is the limited amount of equipment and personnel for ground handling during peak hours. It may also be caused by human error in entering the in-block and off-block time, which is still entered manually.

3.7. PDF Plots and Equations

The pdf plot and equation for each flight category are shown below.

- Full-service carrier domestic narrow-body

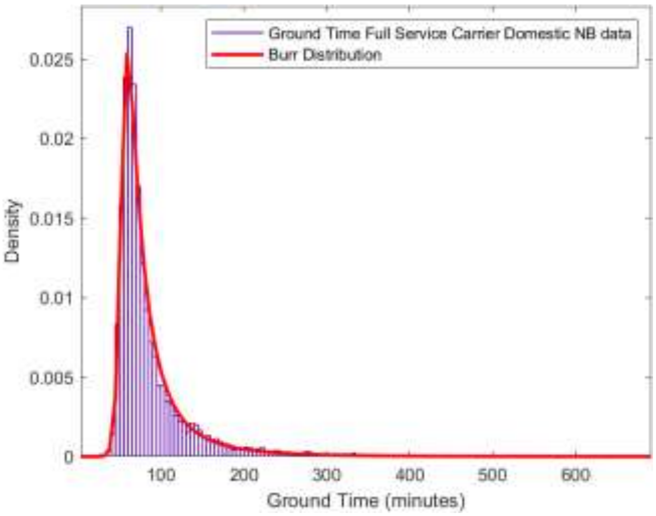

Figure 1. Burr distribution of full-service carrier domestic narrow body ground time data.

$$f(x|\alpha,c,k) = \frac{0.0469\left(\frac{x}{54.2598}\right)^{13.1081}}{\left(1+\left(\frac{x}{54.2598}\right)^{14.1081}\right)^{0.1802}} , x > 0 \tag{5}$$

- Full-service carrier domestic wide-body

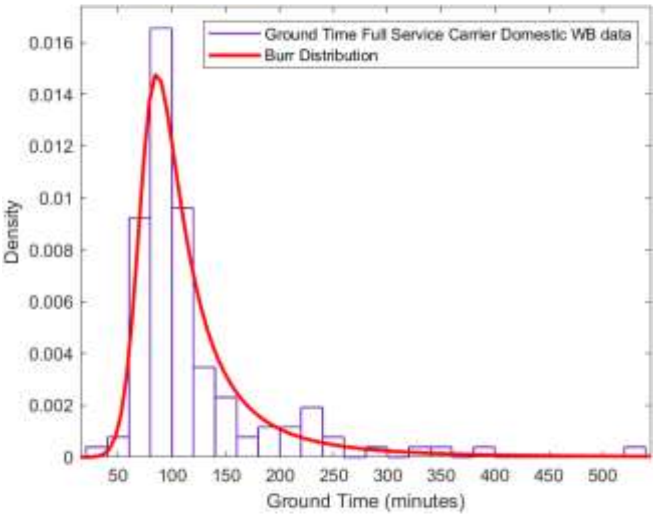

Figure 2. Burr distribution of full-service carrier domestic wide-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.0345\left(\frac{x}{79.1293}\right)^{7.36}}{\left(1+\left(\frac{x}{79.1293}\right)^{8.36}\right)^{1.3268}} , x > 0 \tag{6}$$

- Medium service carrier domestic narrow-body

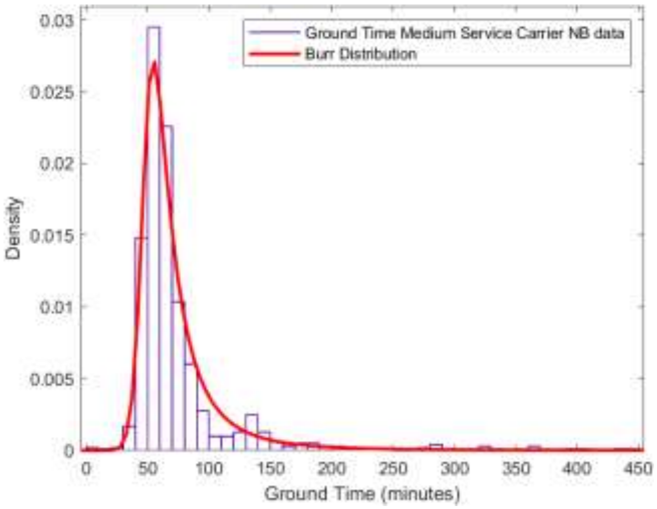

Figure 3. Burr distribution of medium service carrier domestic narrow-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.0469\left(\frac{x}{54.2598}\right)^{13.1081}}{\left(1+\left(\frac{x}{54.2598}\right)^{14.1081}\right)^{0.1802}} , x > 0 \tag{7}$$

- Low-cost carrier domestic narrow-body

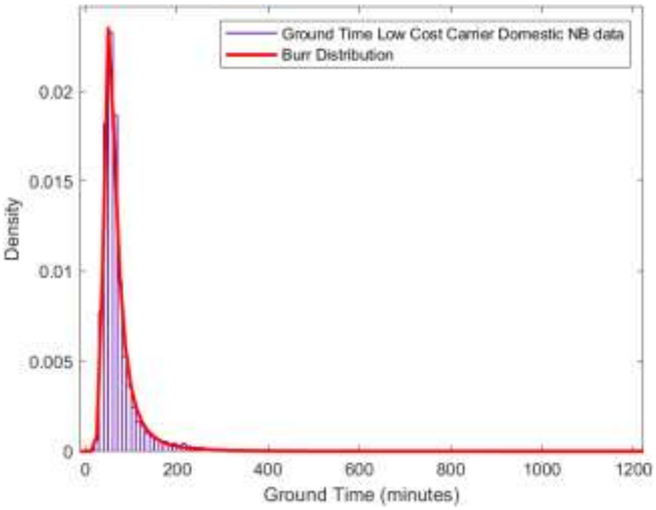

Figure 4. Burr distribution of low-cost carrier domestic narrow-body ground time.

$$f(x|\alpha,c,k) = \frac{0.0568\left(\frac{x}{47.3682}\right)^{6.6887}}{\left(1+\left(\frac{x}{47.3682}\right)^{7.6887}\right)^{1.3498}}\ ,x>0 \tag{8}$$

- Low-cost carrier domestic wide-body

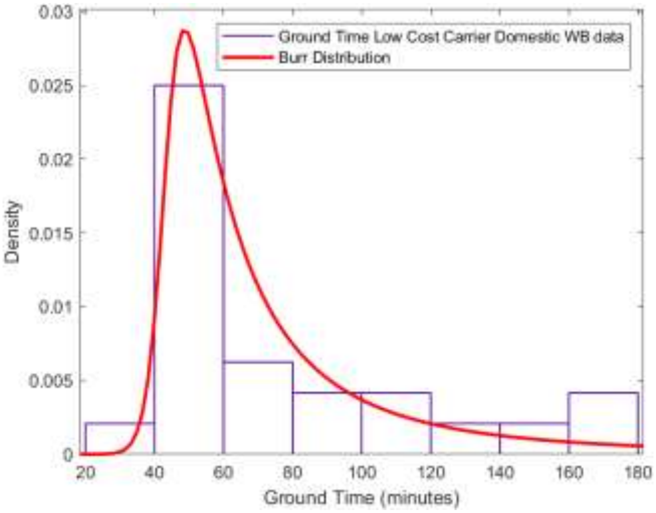

Figure 5. Burr distribution of low-cost carrier domestic wide-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.049\left(\frac{x}{44.1704}\right)^{14.722}}{\left(1+\left(\frac{x}{44.1704}\right)^{15.722}\right)^{1.1376}}\ ,x>0 \tag{9}$$

- Low-cost carrier international narrow-body

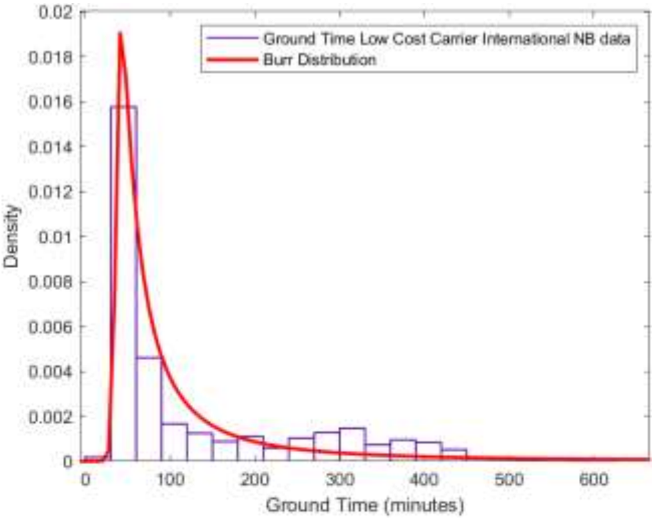

Figure 6. Burr distribution of low-cost carrier international narrow-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.0297\left(\frac{x}{37.2973}\right)^{13.4768}}{\left(1+\left(\frac{x}{37.2973}\right)^{14.4768}\right)^{1.0765}}\ ,x>0 \tag{10}$$

- Southeast Asia Airlines international narrow-body

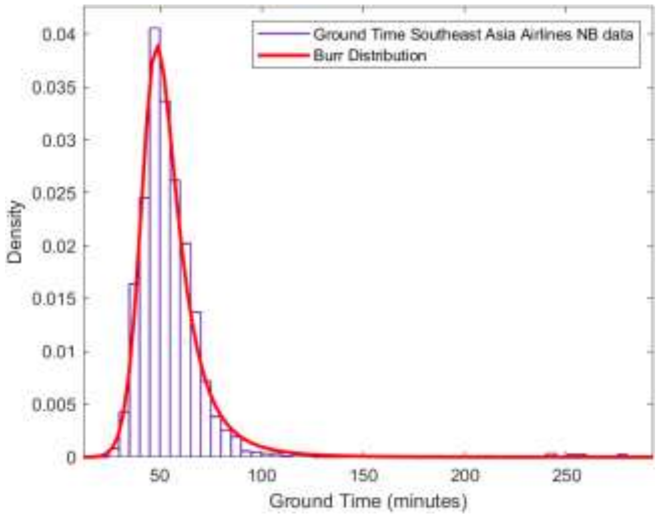

Figure 7. Burr distribution of Southeast Asia Airlines international narrow-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.1126\left(\frac{x}{47.0223}\right)^{8.5379}}{\left(1+\left(\frac{x}{47.0223}\right)^{9.5379}\right)^{1.5549}}\ ,x>0 \tag{11}$$

- Southeast Asia Airlines international wide-body

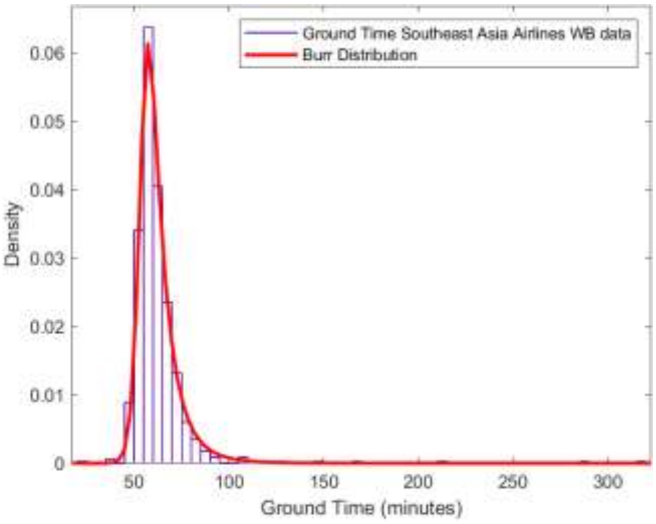

Figure 8. Burr distribution of Southeast Asia Airlines international wide-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.1407\left(\frac{x}{55.1262}\right)^{20.5317}}{\left(1+\left(\frac{x}{55.1262}\right)^{21.5317}\right)^{1.3603}}, x > 0 \qquad (12)$$

- China Airlines international wide-body

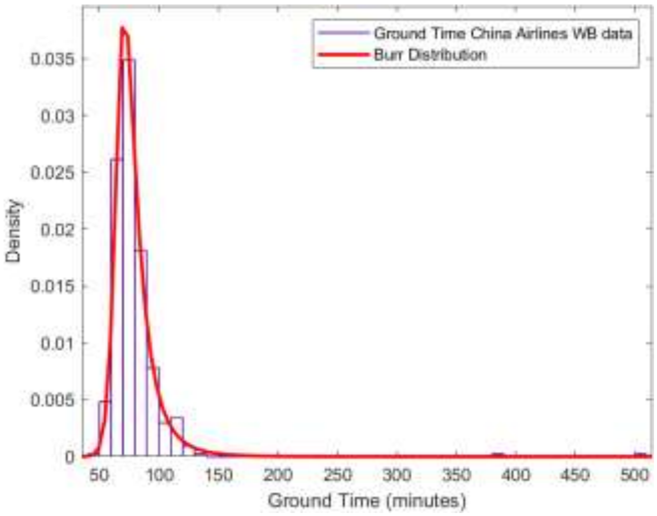

Figure 9. Burr distribution of China Airlines international wide-body ground time data.

$$f(x|\alpha,c,k) = \frac{0.095\left(\frac{x}{68.1627}\right)^{15.1662}}{\left(1+\left(\frac{x}{68.1627}\right)^{16.1662}\right)^{1.4005}}, x > 0 \qquad (13)$$

- Middle East Airlines international wide-body

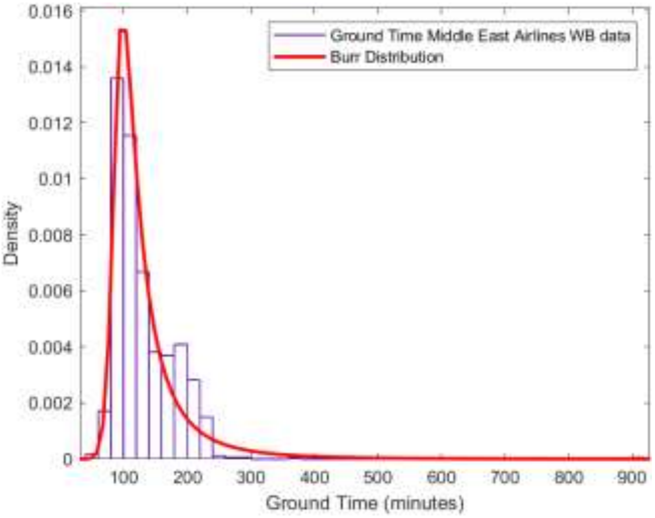

Figure 10. Burr distribution of Middle East Airlines international wide-body ground time data

$$f(x|\alpha,c,k) = \frac{0.0325\left(\frac{x}{90.7552}\right)^{11.0490}}{\left(1+\left(\frac{x}{90.7552}\right)^{12.0490}\right)^{1.2449}}, x > 0 \qquad (14)$$

- Full-service carrier international narrow body

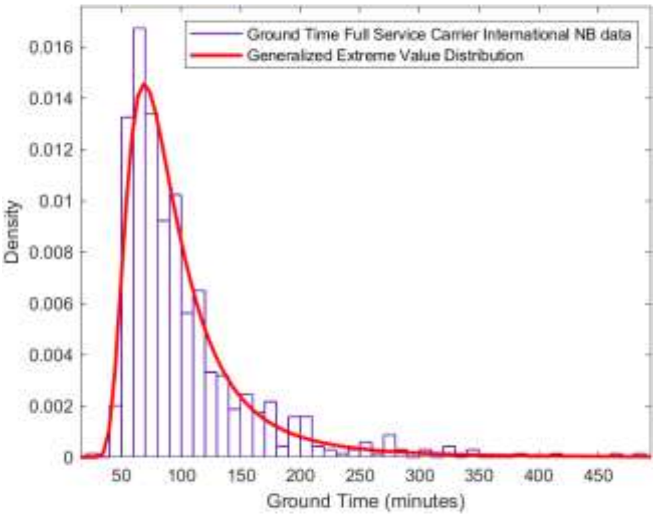

Figure 11. Generalized extreme value distribution of full-service carrier international narrow-body ground time data.

$$f(x|k,\mu,\sigma) = (0.0379)exp\left(-\left(1 + 0.3057\,\frac{(x-75.6069)}{26.372}\right)^{-3.2711}\right)\left(1 + 0.3057\,\frac{(x-75.6069)}{26.372}\right)^{-4.2711} \qquad (16)$$

- Full-service carrier international wide-body

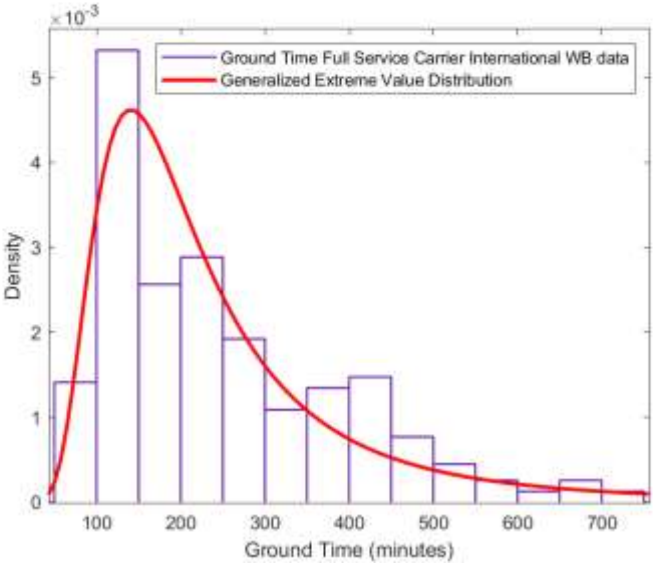

Figure 12. Generalized extreme value distribution of full-service carrier international wide-body ground time data.

$$
\begin{aligned}
&f(x|k,\mu,\sigma)\\
&= (0.0119)exp\left(-\left(1\right.\right.\\
&\left.\left.+\,0.3553\,\frac{(x-164.9154)}{84.2606}\right)^{-2.8149}\right)\left(1\right.\\
&\left.+\,0.3553\,\frac{(x-164.9154)}{84.2606}\right)^{-3.8149}
\end{aligned} \tag{17}
$$

- China Airlines' international narrow-body

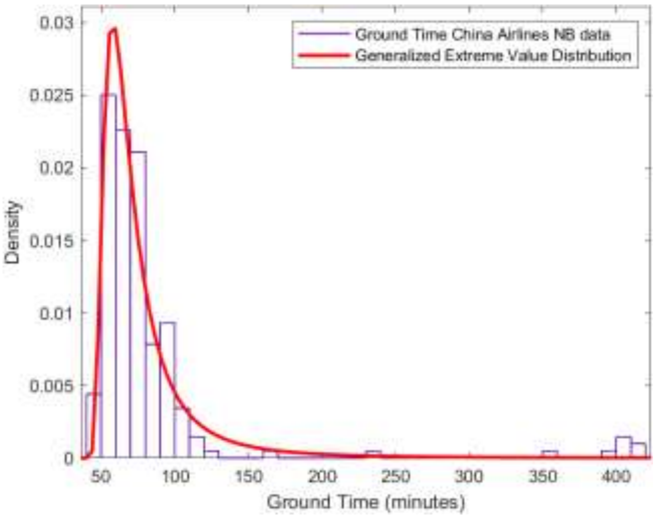

Figure 13. Generalized extreme value distribution of China Airlines international narrow-body ground time data.

$$
\begin{aligned}
&f(x|k,\mu,\sigma)\\
&= (0.0753)exp\left(-\left(1\right.\right.\\
&\left.\left.+\,0.4309\,\frac{(x-62.2656)}{13.2803}\right)^{-2.321}\right)\left(1\right.\\
&\left.+\,0.4309\,\frac{(x-62.2656)}{13.2803}\right)^{-3.321}
\end{aligned} \tag{18}
$$

- Other airlines' international narrow-body

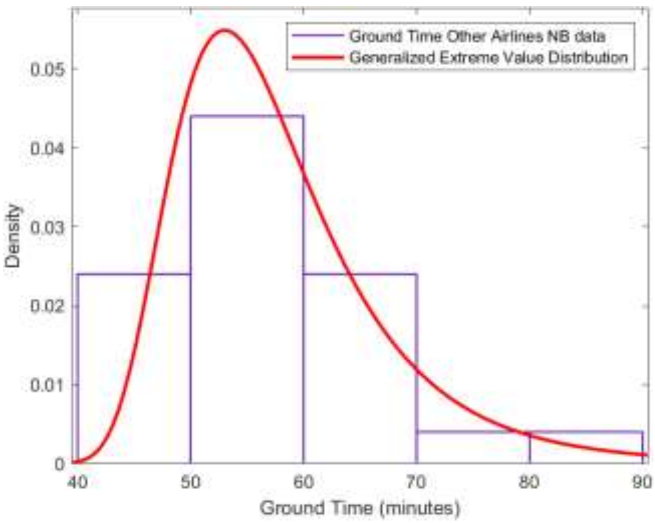

Figure 14. Generalized extreme value distribution of other airlines' international narrow-body ground time data.

$$
\begin{aligned}
&f(x|k,\mu,\sigma)\\
&= (0.1488)exp\left(-\left(1\right.\right.\\
&\left.\left.+\,0.0791\,\frac{(x-53.5137)}{6.7199}\right)^{-12.6393}\right)\left(1\right.\\
&\left.+\,0.0791\,\frac{(x-53.5137)}{6.7199}\right)^{-13.6393}
\end{aligned} \tag{19}
$$

- Low-cost carrier international wide-body

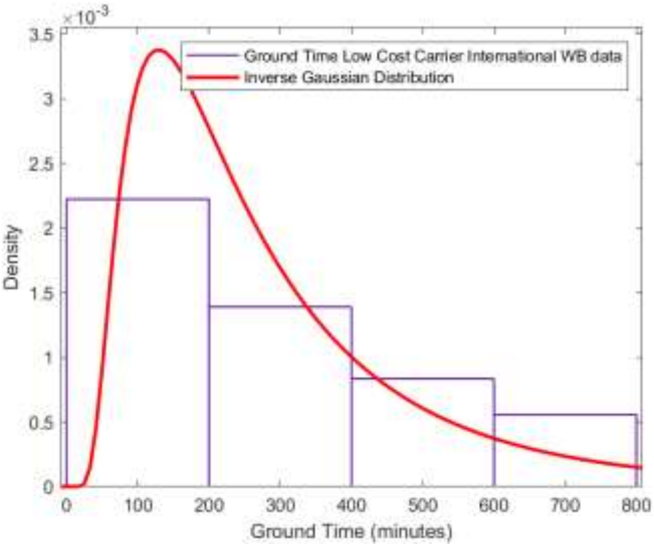

Figure 15. Inverse Gaussian distribution of low-cost carrier international wide-body ground time data.

$$
\begin{aligned}
f(x|\mu,\lambda) = \sqrt{\frac{485.5099}{2\pi x^3}}\exp\left\{-\frac{485.5099}{166272.22x}(x\right.\\
\left.-\,288.33)^2\right\}
\end{aligned} \tag{21}
$$

- Private flights narrow body

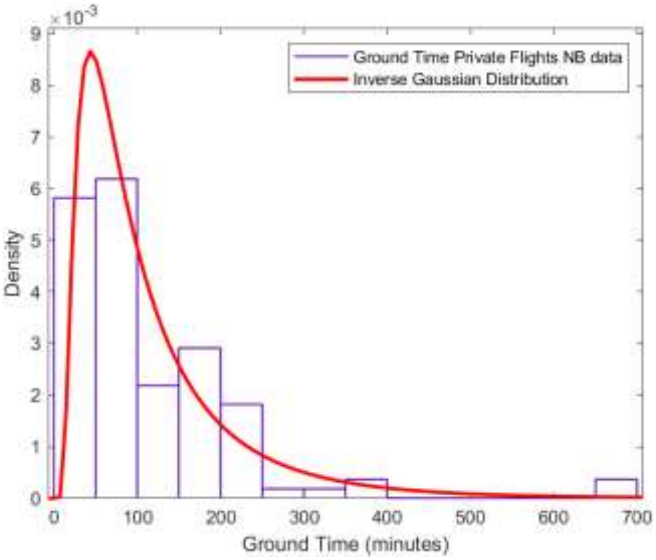

Figure 16. Inverse Gaussian distribution of private flights narrow-body ground time data.

$$f(x|\mu,\lambda) = \sqrt{\frac{152.165}{2\pi x^3}}\exp\left\{-\frac{152.165}{26937.53x}(x - 116.055)^2\right\} \quad (22)$$

- Korea-Japan Airlines International wide-body

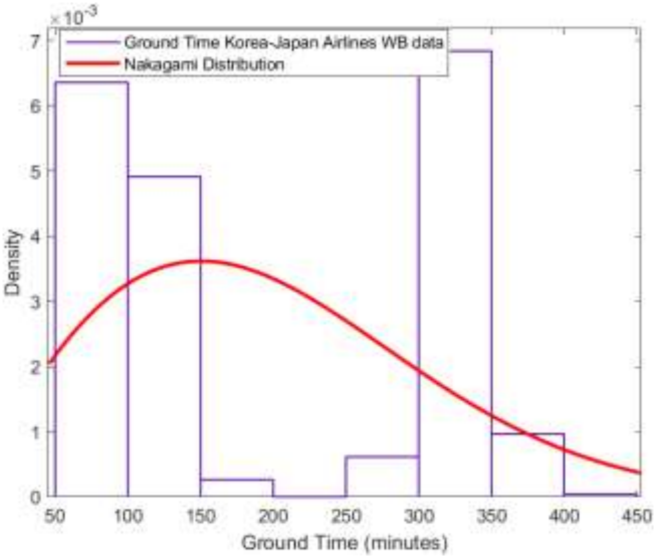

Figure 17. Nakagami distribution of Korea-Japan Airlines international wide-body ground time data.

$$f(x|\mu,\omega) = \frac{0.00011528}{\Gamma(0.8900)} x^{(0.7801)} e^{(-0.00001726x^2)} \quad (24)$$

- Other airlines' international wide-body

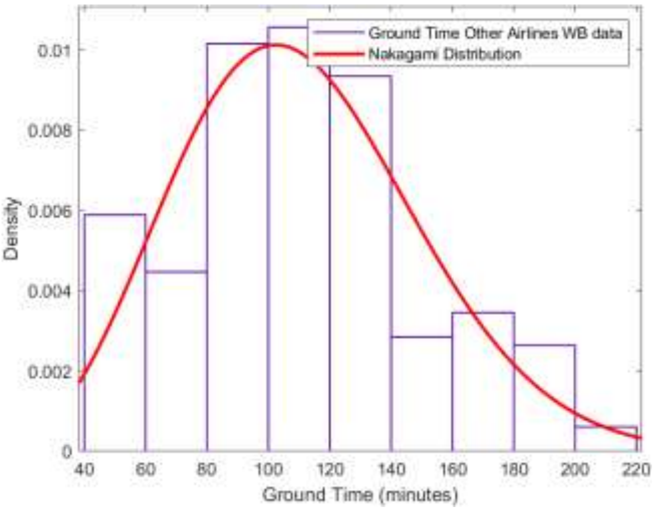

Figure 18. Nakagami distribution of other airlines' international wide-body ground time data.

$$f(x|\mu,\omega) = 1.8097.E - 08 \frac{1}{\Gamma(2.1086)} x^{3.2172} e^{1.5327.E-04x^2} \quad (25)$$

- Cargo flight wide-body

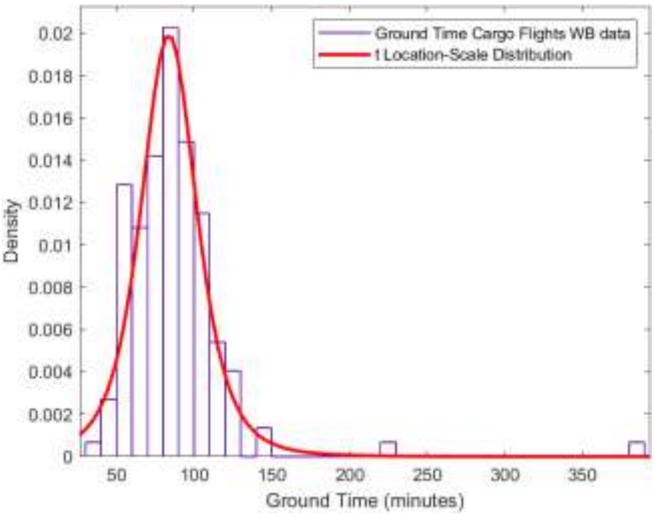

Figure 19. t location-scale distribution of cargo flight wide-body ground time data.

$$f(x|\mu,\sigma,\nu) = \frac{\Gamma(2.3274)}{63.3133\Gamma(1.8274)} \times \left[\frac{3.6549 + \left(\frac{x - 83.7214}{18.6894}\right)^2}{3.6549}\right]^{-2.3274} \quad (27)$$

- Cargo flight narrow-body

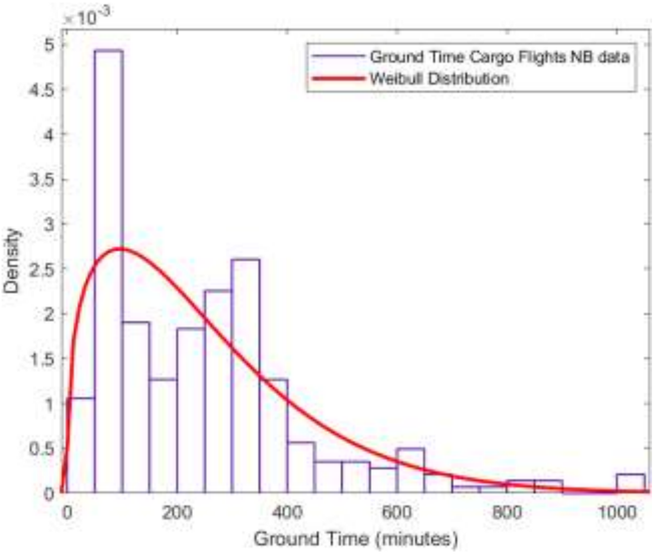

Figure 20. Weibull distribution of cargo flight narrow-body ground time data.

$$f(x|a,b) = 0.0049\left(\frac{x}{269.764}\right)^{0.3336} e^{-(x/269.764)^{1.3336}} \tag{29}$$

4. Conclusion

The aircraft ground time data at Soekarno–Hatta International Airport, which is classified into 20 different categories, fits 6 different types of distribution. Those distributions are Burr, Generalized Extreme Value, Inverse Gaussian, Nakagami, t Location-Scale, and Weibull distribution. Among 6 distributions, the Burr distribution can model ground time data the most. All flight categories have different characteristics from each other depending on the type of operating airline, type of flight, and aircraft size. So, the best-fitted distribution may be different for each category. With the data distribution discovered in this research, the diversity of ground time as the impact of uncertain arrival and departure time can be represented in stochastic models. The result of this research is expected to be able to aid data distribution references for other research related to ground time without primary data collection required.

For further research, the data source is suggested from one year of data to illustrate more the flight variability. The minimum amount of data can be set for each flight category to gain a more precise distribution fitting.

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